CLAIMS

1. An interface apparatus for interfacing motion of a user manipulable object with an electrical system, said interface apparatus comprising:

a user object being physically contacted by a user;

a gimbal mechanism coupled to said user object and providing at least two degrees of freedom to said user object, said gimbal mechanism including a plurality of members, wherein a selected number of said plurality of members are formed as a unitary member in which flex is provided between said selected number of members;

an actuator coupled to said gimbal mechanism for applying a force along a degree of freedom to said user object through said unitary member, wherein said actuator applies said force in response to electrical signals produced by said electrical system; and

a sensor for detecting a position of said user object along said degree of freedom and outputting sensor signals to said electrical system;

whereby said actuator and said sensor provide an electromechanical interface between said user object and said electrical system.

2. An apparatus as recited in claim 1 wherein said gimbal mechanism provides at least two revolute degrees of freedom to said user object, each revolute degree of freedom being about an axis of rotation.

3. An apparatus as recited in claim 1 wherein said gimbal mechanism provides at least two linear degrees of freedom, each linear degree of freedom being along a linear axis.

4. An apparatus as recited in claim 1 wherein said plurality of members of said gimbal mechanism are formed as a closed-loop linkage.

5. An apparatus as recited in claim 4 wherein said closed loop linkage includes four members, wherein said four members of said closed-loop linkage are flexibly coupled to each other as segments of said unitary member.

6. An apparatus as recited in claim 4 wherein said closed loop linkage includes:

a ground member coupled to a ground surface;

first and second extension members, each extension member being coupled to said ground member; and

first and second central members, said first central member having an end coupled to said first extension member and said second central member having an end coupled to said second extension member, wherein said central members are coupled to each other at ends not coupled to said extension members and wherein said central members are coupled to said user object.

7. An apparatus as recited in claim 6 wherein said central members are coupled to an object member which is coupled to said user object.

8. An apparatus as recited in claim 6 wherein said first and second central members are flexible and wherein said first and second central members and said first and second extension members are flexibly coupled to each other and form said unitary member.

9. An apparatus as recited in claim 8 wherein said ground member is rotatably coupled to said first and second extension members by bearings.

10. An apparatus as recited in claim 4 wherein at least one of said members flexibly coupled in said unitary member is relatively narrow in a dimension in which said member is desired to flex, and is relatively wide in other dimensions in which said member is desired to be stiff.

11. An apparatus as recited in claim 7 wherein said first and second central members are flexibly coupled to an object member that is coupled to said object, wherein said object member can rotate in a third degree of freedom about an axis extending approximately through the intersection of said two axes of rotation, said rotation in said third degree of freedom being allowed by flexibility of said central members.

12. An apparatus as recited in claim 11 wherein said actuator is a first actuator coupled to a ground member, and further comprising a second actuator coupled to a ground member of said gimbal mechanism, said second actuator being operative to apply a force in a degree of freedom to said user object in response to signals received from said electrical system.

13. An apparatus as recited in claim 12 further comprising a third actuator coupled to said object for applying a force to said user object in said third degree of freedom, said third actuator being coupled to said ground member and being coupled to said object by a torsion resistant flexure.

14. An apparatus as recited in claim 6 wherein said end of said first central member is rotatably coupled to said first extension member by a bearing, wherein said end of said second

central member is rotatably coupled to said second extension member by a bearing, and wherein said central members are flexibly coupled to said user object.

15. An apparatus as recited in claim 12 wherein said central members are flexibly coupled to an object member which is coupled to said user object.

16. An apparatus as recited in claim 4 wherein said end of said first central member is flexibly coupled to said first extension member, said end of said second central member is flexibly coupled to said second extension member, and said central members are rotatably coupled to said user object by a bearing.

17. An apparatus as recited in claim 4 further comprising a third central member flexibly coupled between one of said extension members and said user object.

18. An apparatus as recited in claim 4 wherein said two degrees of freedom are rotary degrees of freedom, each degree of freedom being about an axis of rotation, and wherein said two axes of rotation are fixed with respect to said ground member, said first and second extension members being rotatable about said fixed axes of rotation, and wherein said central members are rotatable about first and second floating axes, said floating axes being movable with respect to said ground member.

19. An apparatus as recited in claim 1 wherein said user object is a joystick handle.

20. An apparatus as recited in claim 2 further comprising a linear axis member coupled to said gimbal mechanism and being independently translatable with respect to said gimbal mechanism along a third axis in a third degree of freedom, said third axis extending approximately through said intersection of said two axes of rotation, wherein said object is coupled to said linear axis member and is independently translatable along said third axis with respect to said gimbal mechanism.

21. An apparatus as recited in claim 1 wherein said actuator includes a voice coil actuator for imparting a force on said user object using magnetic fields and controlled by an electrical current.

22. An apparatus as recited in claim 21 wherein said voice coil actuator includes a plurality of sub-coils, each of said sub-coils including a different number of loops such that a constant current can be flowed through selected ones of said sub-coils to create different force values on said user object.

23. An apparatus as recited in claim 1 wherein said actuator is interfaced to said electrical system by a voice coil driver chip.

24. An apparatus as recited in claim 23 wherein said voice coil driver chip has a variable gain of voltage input to current output.

25. A method for interfacing motion of a user-manipulable object with an electrical system, the method comprising the steps of:

defining an origin;

providing a gimbal mechanism movable relative to said origin such that a user-manipulable object engaged with said gimbal mechanism has first and second degrees of freedom, said gimbal mechanism having a plurality of members, wherein a selected number of said members are formed as a unitary member such that flex is provided between said selected number of members;

applying a force in each of said two degrees of freedom using a plurality of actuators, respectively, wherein said transducers are decoupled from each other; and

providing said signals to and from said electrical system.

26. A method as recited in claim 25 wherein said plurality of members of said gimbal mechanism form a closed loop of members.

27. A method as recited in claim 25 wherein said actuators are decoupled from each other and grounded.

28. A method as recited in claim 25 wherein said object is independently rotatable with respect to said gimbal mechanism about an axis in a third degree of freedom.

29. A method as recited in claim 25 wherein said object is coupled to said gimbal mechanism at said intersection of said two axes of rotation and is capable of being translated independently with respect to said gimbal mechanism along a third axis in a third degree of freedom.

30. A method as recited in claim 26 wherein said gimbal mechanism includes a unitary flexure of a plurality of members and a ground member, said ground member being rotatably coupled to said unitary flexure by bearings.

31. A method as recited in claim 27 further comprising at least one sensor for converting movement of said object into electrical input signals, said input signals being input to said electrical system.

32. A method as recited in claim 25 further comprising transmitting a force from an actuator included in one of said transducers to said gimbal mechanism using a capstan drive mechanism, said capstan drive mechanism including a cable and pully for transmitting said force.

33. A method as recited in claim 31 wherein said capstan drive mechanism is rotatably coupled to said actuator and a member of said gimbal mechanism, said capstan drive mechanism including a capstan drum coupled to said pully by said cable, wherein said pully is rigidly coupled to said transducer and said transducer is operative to rotate said pulley and thereby transmit force to said gimbal mechanism with no substantial backlash.

34. A method as recited in claim 25 further comprising transmitting a force from an actuator included in one of said transducers to said gimbal mechanism using a friction drive mechanism, said friction drive mechanism including a plurality of rollers frictionally engaging a movable drum, wherein at least one of said rollers is driven by said actuator.

35. A method as recited in claim 33 wherein said friction drive mechanism is rotatably coupled to said actuator and a member of said gimbal mechanism, said friction drive mechanism including a rotatable drum including a drive bar that engages said rollers.

36. A method as recited in claim 27 wherein said first degree of freedom actuator and said second degree of freedom actuator are coupled to a ground member of said gimbal mechanism.

37. An interface apparatus for interfacing motion of a user manipulable object with a host computer system displaying visual images on a screen, said interface apparatus comprising:

a user object movable in a degree of freedom by a user and being physically contacted by said user;

a gimbal mechanism coupled to said user object and providing two degrees of freedom to said user object, said gimbal mechanism including a of a plurality of members;

a processor, separate from said host computer system, for communicating with said host computer system via a communication interface by receiving a host command from said host computer system, said processor being controlled by software instructions;

an actuator physically coupled to said gimbal mechanism and electrically coupled to said processor for applying a force along a degree of freedom to said user object in accordance with a processor command from said processor, said processor command being derived from said host command; and

a sensor for detecting a position of said user object along said degree of freedom and outputting sensor signals to said host computer system, said sensor signals including information representative of said position of said user object.

38. An interface apparatus as recited in claim 37 wherein said plurality of members of said gimbal mechanism are formed in a closed-loop linkage.

39. An interface apparatus as recited in claim 38 wherein said closed loop linkage includes five members, and wherein each of said five members of said closed loop linkage is rotatably coupled to at least two other members of said linkage.

40. An interface apparatus as recited in claim 38 wherein said closed loop linkage includes five members, and wherein a plurality of said five members of said closed loop linkage are flexibly coupled to other members of said linkage.

41. An interface apparatus as recited in claim 38 further comprising:

a linear axis member coupled to said gimbal mechanism and being independently rotatable with respect to said gimbal mechanism about a third axis in a third degree of freedom, said third axis extending approximately through said intersection of said two axes of rotation, wherein said object is coupled to said linear axis member and is independently rotatable about said third axis with respect to said gimbal mechanism; and

a sensor for detecting motion of said linear axis member in said third degree of freedom.

42. An interface apparatus as recited in claim 38 wherein said sensor is electrically coupled to said processor, wherein said sensor outputs said sensor signals to said processor, and wherein said processor sends said sensor signals to said host computer system and utilizes said sensor signals to determine a force output by said actuator.

43. An interface apparatus as recited in claim 42 wherein said processor is operative to provide said processor command to said actuator in accordance with a processor subroutine selected in accordance with said host command and stored in said memory device.

44. An interface apparatus as recited in claim 42 wherein said communication interface includes a serial interface.

45. An interface apparatus as recited in claim 38 wherein said object is a joystick handle.

46. An interface apparatus as recited in claim 38 wherein said object is at least a portion of a medical instrument.

47. An interface apparatus as recited in claim 38 wherein said actuator is coupled to a ground member, and further comprising an additional actuator coupled to a ground member of said gimbal mechanism, said additional actuator being operative to apply a force along a degree of freedom to said user object in response to signals received from said processor.

48. An interface apparatus as recited in claim 37 wherein said actuator is interfaced to said microprocessor by a voice coil driver chip.

49. An interface apparatus as recited in claim 37 further comprising a passive damper element coupled to a member of said gimbal mechanism to increase dynamic stability of said interface apparatus.

50. An interface apparatus as recited in claim 37 further comprising a clock coupled to said processor and used, at least in part, to determine said force output by said actuator.

51. An interface apparatus for interfacing motion of a user manipulable object with an electrical system, said interface apparatus comprising:

a gimbal mechanism including a plurality of members and providing two degrees of freedom to a user-manipulable object coupled to said gimbal mechanism;

a first degree of freedom actuator coupled to said gimbal mechanism, said first degree of freedom actuator including a first voice coil actuator for applying a force to said user-manipulable object in said first degree of freedom using a magnetic field;

a second degree of freedom actuator coupled to said gimbal mechanism, said second degree of freedom actuator including a second voice coil actuator for applying a force to said user-manipulable object in said second degree of freedom using a magnetic field;

at least one sensor for detecting motion of said user-manipulable object along said first and second degrees of freedom and outputting sensor signals to said electrical system;

whereby said actuators and said sensor provide an electromechanical interface between said object and said electrical system.

52. An apparatus as recited in claim 51 wherein said gimbal mechanism includes a closed loop five member linkage, wherein each of said five members is rotatably coupled to at least two other members of said linkage.

53. An apparatus as recited in claim 51 wherein said gimbal mechanism includes a closed loop five member linkage, wherein a plurality of said five members are flexibly coupled to other members of said linkage.

54. An apparatus as recited in claim 53 wherein two of said members are flexible members.

55. An apparatus as recited in claim 51 wherein each of said voice coil actuators includes a coil of wire and a rotatable member that rotates through a magnetic field and is forced in a particular direction depending on a magnitude and direction of a current flowed through said coil.

56. An apparatus as recited in claim 55 wherein said coil includes a plurality of sub-coils, each of said sub-coils including a different number of loops such that constant magnitude currents can be flowed through selected ones of said sub-coils to create different force values on said user object.

57. An apparatus as recited in claim 55 wherein said voice coil includes a first coil of wire used to apply said force to said user-manipulable object, and a second coil of wire used as said sensor for sensing a velocity of said user-manipulable object.

58. An apparatus as recited in claim 51 wherein said user object is rotatable about two axes of rotation, and wherein said user object is independently rotatable with respect to said gimbal mechanism about a third axis in a third degree of freedom, said third axis extending approximately through said intersection of said two axes of rotation, wherein said user-manipulable object is coupled to said linear axis member and is independently rotatable about said third axis with respect to said gimbal mechanism.

59. An apparatus as recited in claim 51 wherein said electrical system includes a host computer system that displays images to said user on a display screen, and wherein said sensor is electrically coupled to a microprocessor provided locally to said interface apparatus, wherein said sensor outputs said input signals to said processor, and wherein said processor sends said input signals to said host computer system.

60. An interface device as recited in claim 59 wherein said processor is operative to provide a processor command to said actuator in accordance with a reflex process selected in

accordance with a host command provided by said host computer, said reflex process being stored in a memory device.

61. An interface device as recited in claim 59 wherein a reflex process is selected by a button on user object that has been activated by said user.

62. An interface device as recited in claim 51 further comprising an electrical interface electrically coupled between said voice coil actuators and said electrical system, said electrical interface including a voice coil driver chip for driving said voice coil actuators.

63. An interface apparatus for interfacing motion of a user manipulable object with an electrical system, said interface apparatus comprising:

a user-manipulable object moveable in two degrees of freedom and physically contacted by a user;

a first degree of freedom actuator coupled to said user-manipulable object, said first degree of freedom actuator including a first voice coil actuator for applying a force to said user-manipulable object in said first degree of freedom using a magnetic field;

a second degree of freedom actuator coupled to said user-manipulable object, said second degree of freedom actuator including a second voice coil actuator for applying a force to said user-manipulable object in said second degree of freedom using a magnetic field; and

at least one sensor for detecting motion of said user-manipulable object along said first and second degrees of freedom and outputting sensor signals to said electrical system;

whereby said actuators and said sensor provide an electromechanical interface between said object and said electrical system.

64. An apparatus as recited in claim 63 wherein each of said voice coil actuators includes a coil of wire and a member that moves through a magnetic field and is forced in a particular direction depending on a magnitude and direction of a current flowed through said coil.

65. An apparatus as recited in claim 64 further comprising a planar member coupled between said user-manipulable object and said first and second degree of freedom actuators, said planar member being translatable in two planar object degrees of freedom, wherein said translation

of said planar member causes said user-manipulable object to move in said user object degrees of freedom.

66. An apparatus as recited in claim 65 wherein said two user object degrees of freedom are rotary degrees of freedom, and wherein said user object is coupled to a ball joint that is rotatable in a socket, and wherein said translation of said planar member causes said ball joint to rotate in said socket and thereby rotate said user object in said two user object degrees of freedom.

67. An apparatus as recited in claim 65 wherein said two user object degrees of freedom are linear degrees of freedom, and wherein said user object is translated in said user object degrees of freedom as said planar member is translated.

68. An apparatus as recited in claim 65 wherein said planar member is a circuit board, and wherein coils of wire included in said voice coil actuators are etched onto said circuit board.

69. An apparatus as recited in claim 68 further comprising an electrical interface electrically coupled between said voice coil actuators and said electrical system, said electrical interface including a voice coil driver chip for driving said voice coil actuators.

70. An apparatus as recited in claim 69 wherein said voice coil driver chip is physically coupled to said circuit board.

71. An apparatus as recited in claim 65 wherein said coil includes a plurality of sub-coils, each of said sub-coils including a different number of loops such that constant magnitude currents can be flowed through selected ones of said sub-coils to create different force values on said user object.

72. An apparatus as recited in claim 65 wherein said coil is a first coil of wire used to apply said force to said user-manipulable object, and further comprising a second coil of wire used as said sensor for sensing a velocity of said user-manipulable object.

73. An apparatus as recited in claim 65 wherein said coil is used both for applying said force to said user-manipulable object and for sensing a velocity of said user-manipulable object.

74. An apparatus for interfacing the motion of a user-manipulable object with an electrical system comprising:

a gimbal mechanism providing two degrees of freedom to an object engaged with said gimbal mechanism about two axes of rotation, said object being coupled to said gimbal mechanism at about the intersection of said two axes of rotation;

an actuator for generating a force along said first degree of freedom of said gimbal mechanism; and

a friction drive mechanism coupled between said actuator and said gimbal mechanism, wherein force from said actuator is transmitted to said gimbal mechanism through frictional contact of members of said friction drive mechanism;

whereby said actuator provides an electromechanical interface between said object and said electrical system.

75. An apparatus as recited in claim 74 wherein said friction drive mechanism includes a rotatable drum having a drive bar, and wherein said members of said fiction drive mechanism include said drive bar and a drive roller coupled to said actuator, said drive roller frictionally engaging said drive bar to rotate said drum and transmit a force to said object in said first degree of freedom.

76. An apparatus as recited in claim 74 wherein said friction drive mechanism includes a translatable drum having a drive bar, and wherein said members of said fiction drive mechanism include said drive bar and a drive roller coupled to said actuator, said drive roller frictionally engaging said drive bar to translate said drum and transmit a force to said object in said first degree of freedom.

77. An apparatus as recited in claim 74 further comprising a second degree of freedom actuator coupled to said gimbal mechanism to generate a force along said second degree of freedom, wherein said first degree of freedom actuator and said second degree of freedom actuator are coupled to a ground member of said gimbal mechanism, and further comprising an additional friction drive mechanism coupled between said second degree of freedom actuator and said gimbal mechanism to transmit a force from said second degree of freedom actuator to said object in said second degree of freedom.

78. An apparatus as recited in claim 75 further comprising a passive roller frictionally engaged with said drive bar on an opposite side of said drive bar to said drive roller.

79. An apparatus as recited in claim 74 wherein said gimbal mechanism includes a closed loop five member linkage, wherein each of said five members is rotatably coupled to at least two other members of said linkage.

80. An apparatus as recited in claim 79 further comprising at least one sensor coupled to said apparatus to sense positions of said object along said two degrees of freedom and which produce electrical signals corresponding to such positions for said electrical system.

81. An apparatus as recited in claim 75 wherein said object includes one of the groups consisting of at least a portion of a surgical tool, a stylus, and a joystick.

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